# ASSESSMENT OF THE BIOMECHANICAL PROPERTIES OF

# *ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION*

# USING DIFFERENT TECHNIQUES OF FIXATION IN A BOVINE KNEE MODEL

DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT OF THE Dr. M G R MEDICAL UNIVERSITY, CHENNAI, FOR THE **DEGREE OF M.S.** BRANCH -II **(ORTHOPAEDIC SURGERY)** MARCH (2005-2007)

## CERTIFICATE

certified that the accompanying dissertation entitled **'ASSESSMENT OF THE BIOMECHANICAL PROPERTIES OF *ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION* USING DIFFERENT TECHNIQUES OF FIXATION IN BOVINE KNEE MODEL'** is the bonafide work by **Dr.C.ANBU SURESH RAO** in partial fulfillment of the requirement for the **DEGREE OF** M.S. Branch **-II** (**ORTHOPAEDIC SURGERY**) of the Tamil Nadu Dr. M.G.R Medical University, Chennai, to be held in March 2007.

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## CERTIFICATE

This is to certify that the dissertation entitled 'ASSESSMENT OF THE BIOMECHANICAL PROPERTIES OF ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION USING DIFFERENT TECHNIQUES OF FIXATION IN BOVINE KNEE MODEL' is the bonafide work by **Dr.C.ANBU SURESH RAO** in the Dept of Orthopaedics and Accident Emergency surgery , Christian Medical College ,Vellore, during his two years (2005-2007) for the **DEGREE OF MS BRANCH -II (ORTHOPAEDIC SURGERY)** in partial fulfillment of requirements for the award of Master of surgery in Orthopaedics by Tamilnadu Dr.M.G.R Medical university

This consolidated report presented herein is based on bonafide study by the candidate himself

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# INTRODUCTION

The importance of secure graft fixation in ligament reconstruction of the anterior cruciate ligament (ACL) has changed dramatically over the last twenty years. Evolving methods of graft fixation has been paralleled by marked changes in the postoperative rehabilitation program (1). In the past, prolonged non weight bearing was recommended to protect the graft (2). Current rehabilitation protocols after knee ligament surgery stress immediate full range of motion, return of neuromuscular function and early weight bearing. In the early postoperative period, graft fixation is the weakest link within the entire system. This early rehabilitation program demands a strong primary fixation of the graft. Thus, rigid fixation of the bone block in the tunnel is crucial for the initial strength of the graft.

Many techniques have been used for fixation of bone patellar tendon bone grafts to bone (3). The gold standard is the interference screw technique introduced by Lambert (4). Subsequently this was improved by Kurosaka et al.(1). Though, the Interference screw provides good fixation strength, it has its own drawbacks like graft laceration, distortion of magnetic resonance imaging, posterior wall blow out and need for hardware removal (5,6).

Since in this technique (i.e. with Interference screws) the patellar block is placed exactly flush with the entrance of the femoral tunnel, a relative mismatch between the length of the graft and length of the tibial tunnel may occur leading to a protrusion of tibial block outside of the tunnel (7). To a certain degree this can be avoided by a distal positioning of the tibial tunnel outlet. However a steep tibial tunnel may not allow transtibial drilling of the femoral tunnel. In these cases a standard Interference screw fixation is not feasible at the tibial site. Staples can be used to fix the tibial bone block in a shallow trough outside of the tibial tunnel entrance (8)

In the department of Orthopedics, Unit-II, we have been using the bone patellar tendon bone graft fixed to the tibia and femur with SS wires tightened over staples for reconstruction. The 20 mm SS wire is passed through the tibial end of the graft, and then tightened over a staple, which is placed perpendicular to the tibial surface a cm away from the tibial bone tunnel. This technique is simple, is less expensive, is less exacting - in that the position of the bony segments of the graft can be adjusted to avoid protrusions through the tibial or femoral tunnels, and a posterior blow out of the femoral tunnel does not impede fixation. The biomechanical efficacy of this fixation technique has not been evaluated.

Another factor to be considered while evaluating the biomechanical properties and efficacy of the fixation device is the tension of the graft. Initial tension applied to the graft is considered to be among the important factors that influence the result of anterior cruciate ligament reconstruction (9). The effect of initial graft tension on the function of the reconstructed knee has been examined in previous in vitro and in vivo studies (10-15). It has been reported that a discrepancy exists between the *initial set force* and *residual force* of the graft after fixation (16). Each fixation method has different properties affecting the achievement and maintenance of graft tension. Residual tension of the tendon graft after fixation is different from the tensile load applied to the graft during fixation and the mechanical behavior during and after fixation is specific to the fixation method employed in the procedure(17,18).Thus, this factor too needs to be evaluated while assessing the biomechanical properties of the different fixation devices.

# AIMS & OBJECTIVES

**1.** To evaluate the biomechanical properties of bone patellar tendon bone graft fixed with three different techniques in a bovine tibial model:

- **a) INTERFERENCE SCREW**
- **b) STAPLE WITH STAINLESS STEEL WIRE**
- **c) SCREW FIXATION POST WITH POLYESTER (No.5' ETHIBOND)**

The parameters to be evaluated include

- **Ultimate failure load (Pullout strength)**
- **Stiffness**
- **Mode of failure**

2. To compare the Set force (**Initia**l **load** given to the graft before fixation) and **Residual load** (tension in the graft after fixation) in the implanted graft fixed with the three different fixations techniques.

# REVIEW OF LITERATURE

The knee joint is a complex hinge joint and has principle motions of flexion and extension. The ligaments and other supporting soft tissue structures (joint capsule, muscles, tendons and menisci) control the stability of the knee (20). The Anterior Cruciate Ligament (ACL) is the primary restraint preventing anterior displacement of the tibia relative to the femur. It also serves as an important secondary restraint to varus-valgus movements, as well as internal-external rotation (21). It is the most commonly injured ligament in the knee.

The tibial origin of the ACL is in the anterior part of the intercondylar area just posterior to the attachment of the medical meniscus and anterior to the lateral meniscal attachment. It is directed superiorly, posteriorly and laterally through the intercondylar notch to attach to the posteromedial aspect of the lateral femoral condyle (22). It has three bundles - anteromedial, intermediate and posterolateral – which are named according to their tibial attachment.

## ACL reconstruction

### Technique

Currently, endoscopic intra-articular reconstruction with a biologic graft is the procedure of choice for the treatment of a rupture of the ACL. Diagnostic arthroscopy is commonly performed initially to confirm the injury, and identify other associated injuries. The ACL stumps and intercondylar notch are cleared. The intercondylar notch may require notchplasty to prevent graft impingement. After graft harvesting and preparation, the tibial and femoral tunnels are drilled to the corresponding graft size. The prepared graft is then pulled through the tibial tunnel into the femoral tunnel with the aid of passing sutures and the femoral side of the graft is secured first. The tibial side of the graft is then secured, while tension is applied to the graft.

## Graft Placement

Placement of the graft in the tibia and the femur has been considered one of the most critical factors in determining the outcome of ACL reconstruction (23). Incorrect tibial or femoral tunnel placement results in changes in the graft motion and tension, and this may restrict knee motion or result in joint laxity(23).

In the tibia, a tunnel placed too anteriorly can cause impingement. This leads to increased graft tension in full extension and in full flexion. This leads to a higher incidence of early graft failure (24). A tibial tunnel placed too posteriorly causes excessive laxity during flexion. Often the PCL can be injured while drilling the femur in such a situation(25).

In the femur, the tunnel is currently placed to the insertion of the anteromedial bundle. The femoral tunnel is commonly drilled to at 11 o'clock position for the right knee and at 1 o'clock position for the left knee. This is believed to reproduce the anteromedial bundle of the ACL. A femoral tunnel placed too posteriorly causes increased graft tension in flexion, while one placed too anterior is associated with increase in graft failure rates (26).

**Graft preconditioning**

The preconditioning of the graft prior to fixation and the initial graft tension at the time of fixation (also referred to as the ***initial load***) are considered as important factors determining the long-term function of the reconstructed knee(9). Under a constant load, the graft elongates (i.e. creep) over time.

The ideal graft tension during graft fixation is controversial. In a prospective randomized study, Yasuda et al. (13) observed that hamstring tendon grafts pretensioned to 80 Newton's (N) before fixation resulted in significantly less knee laxity at 2 years compared with those pretensioned at 20 N or 40 N. Zeminski et al(46) used cadaver knees and quadrupled hamstring grafts to study the effects of high initial graft tension on the biomechanical outcome of an ACL reconstruction. In contrast to Yasuda et at.(13) they concluded that the reconstructed knee is sufficiently stabilized by 44 N of initial tension and doubling the tension did not significantly increase the knee stability. An excessive graft tension might restrict joint motion and consequently result in damage to the articular cartilage. Excessive graft tension may also have adverse effects on the postoperative healing process and result in less than optimal biomechanical properties of the graft (14,15). Conversely, inadequate graft tension may possibly fail to re-establish the stability of the knee.

The degree of knee flexion during graft fixation has also been shown affect graft tension. It has been shown that in full extension the distance between the femoral tunnel and the tibial tunnel will be longest. As a consequence, a graft fixed at full extension will slacken during flexion. Conversely, a graft fixed at 30 degrees of knee flexion will tighten as the knee is extended. In a cadaveric study, Hoher et at. (27) found that a hamstring graft fixed at 30 degrees of flexion with 67 N posterior tibial load most closely re-established ACL function.

As mentioned above, initial load applied to the graft is considered to be among the important factors that influence the result of anterior cruciate ligament reconstruction (9). This has been assessed in various studies (13-15 ,17,18). However, it has been reported that a discrepancy exists between the *initial load* and ***residual load*** of the graft after fixation (16). Each fixation method has different properties affecting the achievement and maintenance of graft tension (17,18). Residual tension or load of the tendon graft after fixation is different from the tensile load applied to the graft during fixation i.e. the initial load, and the mechanical behavior during and after fixation is specific to the fixation method employed in the procedure.

## Types of Grafts

The two types of biologic substitutes used in intra-articular reconstruction for ruptured ACL are *autografts* and *allografts.* The most commonly used autografts are bone-patellar tendon-bone (BPTB), multiple strand hamstring tendons and quadriceps tendon-bone, whereas the two most commonly used allografts are BPTB and Achilles tendon-bone (28).

Bone patellar bone tendon is the gold standard for ACL reconstruction (9,28). The popularity of BPTB graft is based on its structural properties, quality of fixation, and the fact that it provides bone-to-bone healing (29). The major concern with the use of BPTB graft has been the donor site morbidity, anterior knee pain, kneeling discomfort, loss of motion, and weakness of the quadriceps muscle (28,30). Fractures of the patella have also been reported(31).

The relatively low donor-site morbidity and relatively good results have resulted in the increased popularity of the hamstring graft (28,29). Multiply looped hamstring grafts have been shown to have initial ultimate tensile load and stiffness similar or higher than the normal ACL (30). However, some of the concerns have been the failure to achieve rigid initial fixation to bone, slower bone incorporation compared to the BPTB graft, increased knee laxity, potential hamstring muscle weakness, and the discomfort associated with some of the fixation hardware (28,29).

The quadriceps tendon-bone graft has also been used for ACL reconstruction (28). It is commonly used for revision ACL reconstructions and for multiple ligament reconstructions (28).

Allografts are commonly harvested sterile and preserved by deep freezing, or secondarily sterilized by low-dose gamma irradiation (32). Accordingly the allografts are today most commonly proposed for multiple ligament reconstructions and for revision surgery (28,32). The disadvantages of allograft include the fear of disease transmission, loss of structural properties with freezing and sterilisation, and delayed graft incorporation (28,29).

**Table 1.**

**Biomechanical properties of the normal ACL and commonly used autografts**.

| | Ultimate failure Load (N) (Mean ± SD) | Stiffness (N/mm) | Reference |
|---|---|---|---|
| ACL | 2160 ± 157 | 242 | (19) |
| ACL | 2195 ± 427 | 306 | (33) |
| Doubled semitendinosus and gracilis graft | 1709 ± 581 | 213 | (34) |
| Doubled semitendinosus and gracilis graft | 2428 ± 475 | 310 | (34) |
| Quadrupled STG graft | 2421 ± 538 | 238 | (35) |
| BPTB (10mm) | 1953 ± 325 | 423 | (36) |
| BPTB (10 mm ) | 1784 ± 580 | 210 | (35) |
| Bone-quadriceps tendon | 2172 ± 618 | 312 | (36) |

## ACL graft fixation

Graft fixation site is the weakest link in the ACL reconstruction during the immediate postoperative period until incorporation occurs within the bone tunnel. (37,38). Graft incorporation can take 6 to 12 weeks to occur after the reconstruction (37). Many methods of graft fixation have been used, including staples, sutures over a screw post, sutures tied to an endobutton, screws and washers, transfixations, and interference screws of various materials. Fixation devices are classified as direct or indirect (37). In indirect fixation, there is a connecting material, like an ethibond suture which is attached to the graft, and this connecting material is anchored to the bone. In direct fixations, the graft is fixed directly to the bone by the device.

### *Ideal graft fixation*

For an ideal ACL graft fixation, there should be sufficient initial strength to avoid fixation failure i.e. the ***ultimate failure load***, or ***the pull out strength*** of the fixation should be high. There should be sufficient resistance to slippage under cyclic loading conditions to avoid gradual loosening in the early postoperative period after ACL reconstruction. In addition, there should be sufficient ***stiffness*** - to restore the stability of the knee and to minimize graft-tunnel motion. An ideal graft fixation should be anatomic, biocompatible, safe and reproducible, allow undisturbed post surgical MRI evaluation of the knee, and not complicate revision surgery if required (28).

It has been estimated that the graft is loaded to approximately 150-500 N during normal activities (39,40). Noyes et al.(39) estimated that the ACL is loaded to approximately 454 N (20 % of its strength in biomechanical testing) during normal activities. The fixation of the graft has to be strong enough to withstand these forces i.e. the *ultimate failure load* or the *pull out strength* has to be greater than these forces.

Fixation of the graft is regarded as the least stiff point in the graft-fixation device- construct. Sufficient *stiffness* of the graft fixation construct not only restores the normal load-displacement response of the knee, but also diminishes graft motion within the bone tunnel. In indirect fixation methods, the graft fixation is at a distance from the articular tunnel opening (e.g endobutton in the femur). The stiffness of the graft would be reduced as a result. This indirect fixation also allows the graft to move in a longitudinal and a sagittal plane during knee motion (28,41). Longitudinal and sagittal graft motions within the bone tunnel are referred to as the *bungee cord effect and windshield wiper effect,* respectively. Excessive graft-tunnel motions lead to impaired graft incorporation and enlargement of the bone tunnels, thereby altering the biomechanical function of the knee after ACL reconstruction (28,38). Both BPTB and soft tissue grafts have been shown to cause tunnel enlargement (42).

To achieve high stiffness, the ideal fixation should be at the tunnel opening (near the articular surface). This minimizes graft motion relative to the bone tunnel and improves stability (43). Therefore, fixation with devices like the interference screw or transfixations devices would have high stiffness.

## BPTB graft fixation

Abundant research has shown that for Bone-Patellar Tendon-Bone grafts, the tibial fixation is generally the weak point (41). The *pull out strength* of the graft depends on the fixation device used. Fixation of the graft closer to the surface of the joint may offer theoretically superior stability of the joint due to an increased *stiffness.*

### *Cortical fixation*

Steiner et al.(43) used a human cadaveric model to evaluate four different BPTB graft fixation methods. They found that suture fixation of BPTB grafts produced lower *stiffness* compared to interference screw fixation. Combination of interference screw and suture techniques provided highest *ultimate failure load* (or *pull out strength*) and *stiffness* (43). Recently, Honl et al. (44) compared three different BPTB graft fixation methods (button, interference screw and sutures tied over a screw post) using a cyclic loading test. They found with interference fixation, the biomechanical properties were age dependant. For patients over 40 to 45 years, button was found to have a better fixation - with higher pull out strength. They stated that a suture tied over a post was not suitable for graft fixation under clinical circumstances, as in addition to inferior stiffness of the sutures, the prominent screw post could irritate the patient, and would require removal later. At the femoral side, sutures tied over a screw post would require a lateral thigh incision.

***Interference screw fixation***

There are several factors that affect the initial graft fixation strength (*pull out strength*) of the interference screw. They include the quality of the bone, the shape of the bone block, the gap between the screw and the bone block, the divergence of the screw, design, material and size of the screw (45). Posterior wall blow out/ tibial tunnel explosion too precludes the safe use of interference screws.

Interference screw divergence i.e. the angle of the interference screw with respect to the bone block - is a common clinical concern. It has been shown that an increase in the divergence angle decreases fixation strength at angles greater than 20 degrees (46,47).

The gap between the bone tunnel wall and the bone block also affects the initial fixation strength. Butler et al. (48) demonstrated that when the gap size was 3 or 4 mm, the *ultimate failure load* ( *pull out strength*) was significantly better using a 9 mm diameter screw instead of a 7 mm diameter screw.

During endoscopic ACL reconstruction using the BPTB graft, the surgeon may encounter problems associated with graft-tunnel mismatch. The length of the BPTB graft may exceed the combined tunnel and intra-articular distance, with the consequent problem of the bone block protruding out of the tibial tunnel. The incidence of graft-tunnel mismatch has been reported to be as high as 28 % (49). However, this can be decreased by increasing the length of the tibial tunnel, or alternatively, advancing the femoral bone block further within the femoral socket.  Also, after the femoral fixation, the BPTB graft can be shortened by flipping the patellar tendon or by recessing the tibial bone block . Other suggested fixation options for the BPTB bone block protruding distally outside the tibial tunnel are sutures tied over a screw post, and staples (50). This situation precludes the use of interference screws.

## Soft tissue graft Fixation

### *Cortical fixations*

*Staples* have been used to fix the graft directly onto bone. Single staple fixation had poor results in biomechanical studies(3). However, the result improved considerably when two staples were used( (50,52). Using a "belt-buckle" technique Magen et al (51) fixed the porcine extensor tendon to the tibial cortex, and found the pull out strength to be 704 ± 174 N and stiffness 118 ± 47 N/mm.  Staple fixation is, however, at distance from the joint surface, and hence the stiffness is theoretically less. The prominence of the staples may cause irritation at the fixation site and can require removal later. Staples are currently recommended as a back-up for other fixations of the soft tissue graft(53).

Indirect soft tissue graft fixation options rely on connecting materials (sutures, and polyester tapes), which connect the graft to the point of actual fixation. Tying *sutures over a screw post and washer/ button* placed just outside the bone tunnel has been used for indirect fixation both on the femoral and tibial side. Yamanaka et al. (52) found that it had *ultimate failure load* of 458 ± 72 N and the stiffness was only 19.8 ± 1.4 N/mm. The disadvantages of this technique include the lateral thigh incision on the femoral side. The strength and stiffness of the fixation post – graft complex is dependant on the stiffness and ultimate failure load of the suture connecting the graft and the fixation device.

*EndoButtons* have been found to provide a quick, simple, reproducible and strong method for the femoral site hamstring graft fixation. EndoButton consists of a small titanium button and a connecting material. The button is placed on the lateral femoral cortex of the femur and connecting material is attached to the button . This connecting material forms a loop on which the graft is fixed. The disadvantage of the EndoButton technique is the possibility of the bungee effect and the windscreen wiper effect.

### ***Interference screw fixation***

Recent reports comparing the biomechanical properties of interference fixation with that of other fixations in soft tissue graft have been controversial (51). Magen et al. (51) evaluated the fixation properties of different tibial soft tissue fixation methods. Using the human tibia and quadrupled hamstring grafts, the tandem washers and washerLoc provided significantly higher yield load. The yield value provided by interference fixation was only 350 ± 134 N. In addition, 4 of the seven interference fixations failed at 500 N or lower. Although the results from biomechanical studies of hamstring graft interference screw fixation in human bone have not been very encouraging (51), the method has gained wide acceptance, because clinical outcome reports have been promising.

Many factors contribute to the strength of the initial fixation ( i.e. *pull out strength*) of the soft tissue graft including the density of the bone, the insertion torque of the screw and diameter, length, design and material of the screw (54,55). As with the BPTB graft, fixation with the interference screw will be compromised if there is a posterior tunnel blow out, or tibial tunnel explosion. In addition, there is always a possibility of graft laceration during insertion.

As a result of the relatively poor pull out strength, and slippage of the graft when subjected to cyclical loads, when using the interference screw soft tissue fixation in the tibia, a back-up fixation is often recommended. (43)) Interference screws have the theoretical advantage of lowering the stiffness.

Bio absorbable screws have been shown to have good biomechanical properties, but complications of breakage during insertion, inflammatory synovitis have been reported (56).

***Transfixation***

In the transfixation technique the implant is placed transversely through the femoral or tibial bone tunnel to secure the graft. The tendon is looped around a crossbar inserted into the metaphysial part of the lateral femoral condyle. Alternatively, as in Rigifix, the tendon is held by cross wires. The tendon is then tensioned and fixed onto the tibia subsequently. There is good pullout strength and stiffness (57) Transfixation seems to approach the criteria for the ideal graft fixation technique for the femoral side –in terms of initial fixation strength (or *pull out strength*) and *stiffness*.

## Laboratory assessment of the Biomechanical properties of ACL reconstructions

***Tissue source for biomechanical studies***:

Many different tissue sources have been used to evaluate ACL graft fixation, including human, porcine, and bovine (1,58). It would be ideal to use human cadaver specimens from young healthy donors to evaluate the structural properties of ACL graft fixation, but since human tissues are difficult to obtain, animal tissues have been used widely in biomechanical experiments. Bovine knees are the most popular animal tissues source as described by Weilers et al (5,6). They have been considered to mimic human knee specimens in terms of their size, shape, and bone quality. However, there is evidence that the structural properties of a fixation method vary between animal and human tissue (51). Porcine knees have been shown to have clearly higher bone density compared to human bones. In addition, Magen et al (51) found substantially lower yield loads when interference screws were used to fix hamstring tendon grafts in human bone compared with porcine tendons fixed in procine bone. They concluded that caution is warranted when animal tissues are used to predicting the performance of interference screws in human ACL fixation.

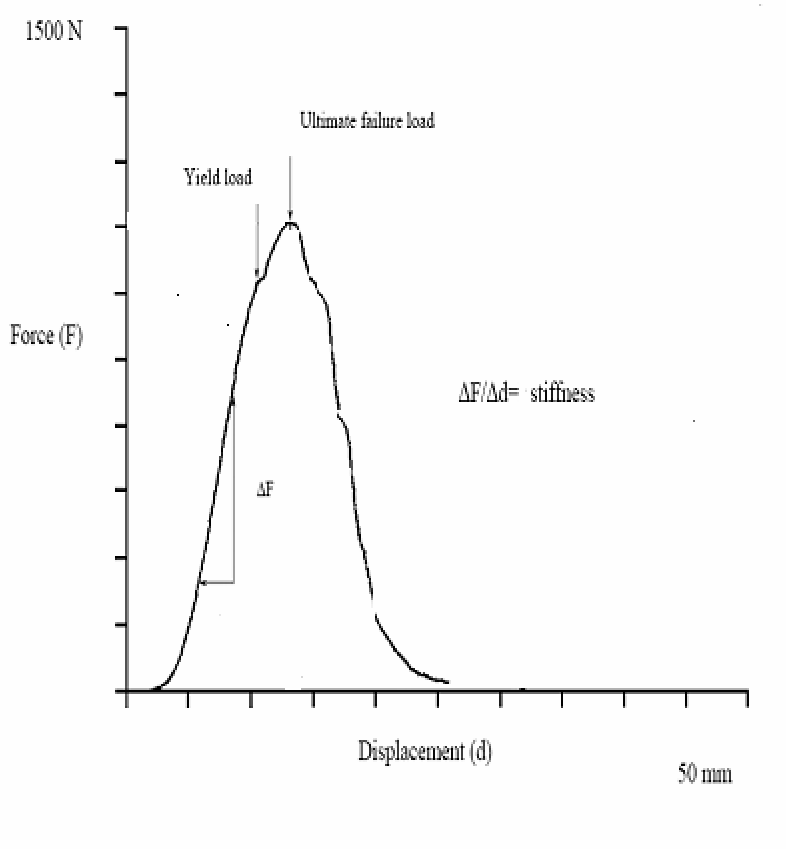
As the quality of human bone specimen often varies considerably, porcine and bovine knee specimens with more uniform bone quality offer a reasonable alternative to human bone. The increase in bone density mainly affects fixation that rely on interference to secure the graft within the bone tunnel. Therefore, results from animal studies evaluating interference fixation are presumably overly optimistic in comparison with the situation in humans.

ACL graft fixation have been evaluated extensively in numerous laboratory studies. It is somewhat difficult to compare the studies because the experimental methods of the studies have varied so widely.

***Assessment of the structural properties of graft fixation complex:***

To study the biomechanical properties of the ACL, and it's substitutes, it is essential to study their response when loaded. The single load-to-failure test is designed to determine the structural properties of a graft fixation construct during a single overload mimicking a traumatic incidence. The response of the specimen to loading is obtained in the form of force-displacement curve (Fig 1). After an initial period of low stiffness, (a small increase in load producing large elongation), further loading produces a nearly linear curve. Since the ***stiffness*** of any loaded construct is calculated as the ratio of force displacement, this linear portion of the curve provides us with the slope of the curve, based on which the stiffness is calculated.

**FIG-1 FORCE –DISPLACEMENT GRAPH**




The ***yield / linear load*** is defined as the force at which the slope of the force-displacement curve first clearly decreases. The first significant slippage of the ACL graft typically occurs at the yield load point, it thus represents the beginning of abnormal laxity. Beyond the yield point, the force-displacement curve is usually non-linear. The other parameter assessed is the ***ultimate failure load*** or the ***pull out strength*** – the load at which the graft is pulled off the tibia. (28)

The normal ***pullout strength*** of the normal ACL is 2160 ± 157 and ***stiffness*** is 242 ± 28N(26) (39).

# MATERIALS AND METHODS

**FIG –2** TIBIAL SPECIMEN WITH BONE PATELLAR TENDON BONE (BPTB)

**FIG –3** BONE MINERAL DENSITY (BMD) OF TIBIAL SPECIMEN

*DEXA scan showing BMD at screw insertion site>0.8/cu.cm*

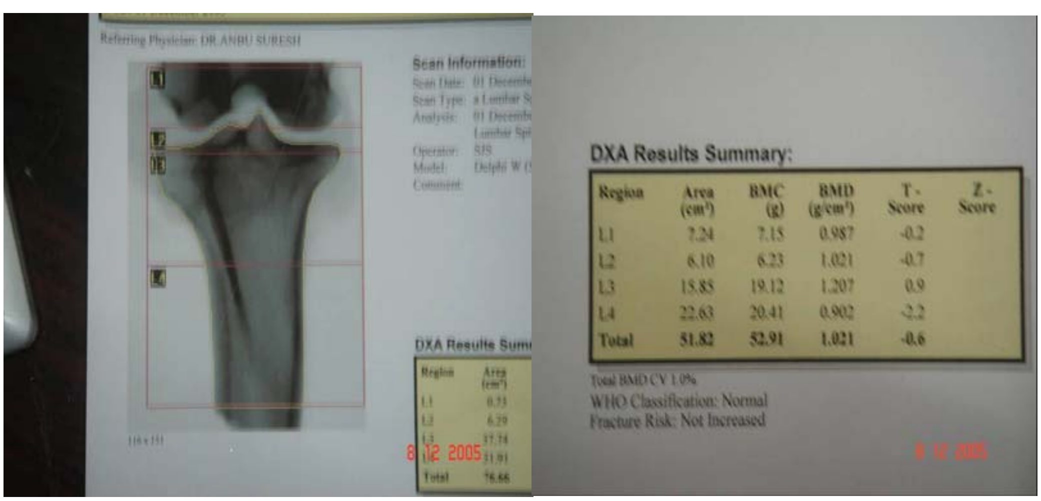


**FIG –4** TIBIAL FIXATION

*Tibial specimen held by vice grip & cross pins*

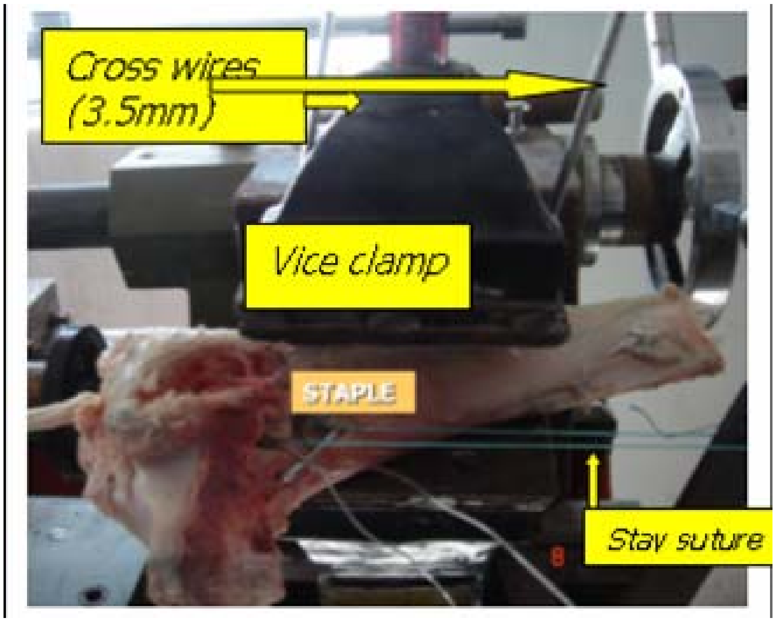



**FIG –5** BPTB GRAFT

*7mm hole made in patella –to serve as fixation to the load cell*

A total of 15 fresh bovine knees were obtained from local slaughter house. The ligaments, soft tissues and menisci were dissected off the tibia, and the femur discarded. The patella and the patellar tendon were left attached to the tibia *(fig-2*). To assess the bone mineral density of the tibia, the tibial specimen was scanned using the DEXA as in *fig-3*. The purpose of the scan was to ensure that the screw insertion site had a trabecular bone density of greater than 0.8g/cu.cm. After the DEXA scan was performed, a 30mm x 10mm quadrilateral bone plug was harvested from the bovine tibia. The patella was left intact attached to the patellar tendon, which was made to 10mm width.

**TIBIAL SPECIMEN PREPARATION:**

A 10mm diameter bone tunnel was drilled from the tibial ACL insertion, directed antero-medially in an inside out fashion. The tibia was mounted on the testing apparatus and fixed using a modified vice grip and further stabilized by two 3.5mm cross pins that were passed through the vice grip and in to the tibial specimen (fig-4). During the testing process the specimen was kept moist with normal saline

**PATELLAR TENDON GRAFT PREPARATION**:

A 7mm hole was made in the patella –to serve as a fixation point to the load cell. (*fig-5)* The 30x10mm tibial bone plug was then prepared for fixation with different techniques. Two 2mm hole were drilled in the bone block.

**FIG –6** BPTB GRAFT WITH SS WIRE & polyester stay suture
*20mmG SS wire placed in proximal hole*


**FIG –7** BPTB GRAFT WITH No.5 ETHIBOND & polyester stay suture
*No.5Ethibond placed in proximal hole*

**FIG-8**

*BPTB graft attached to the load cell by a 'S' shaped hook*

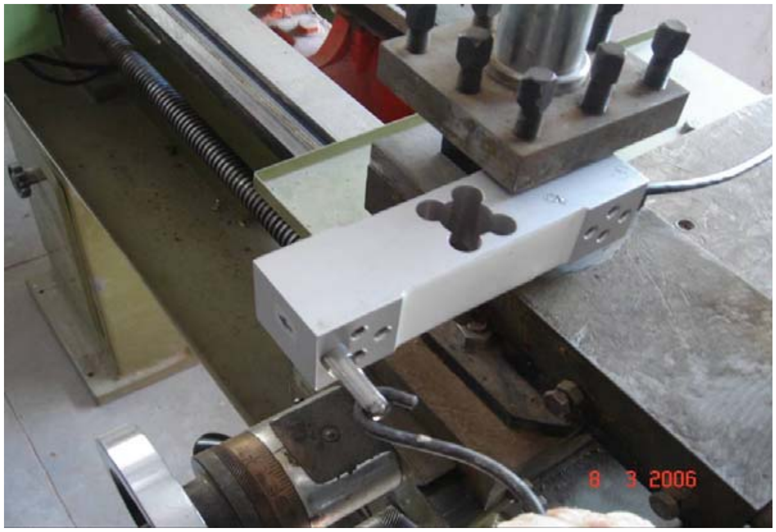



**FIG –9** OSCILOSCOPE

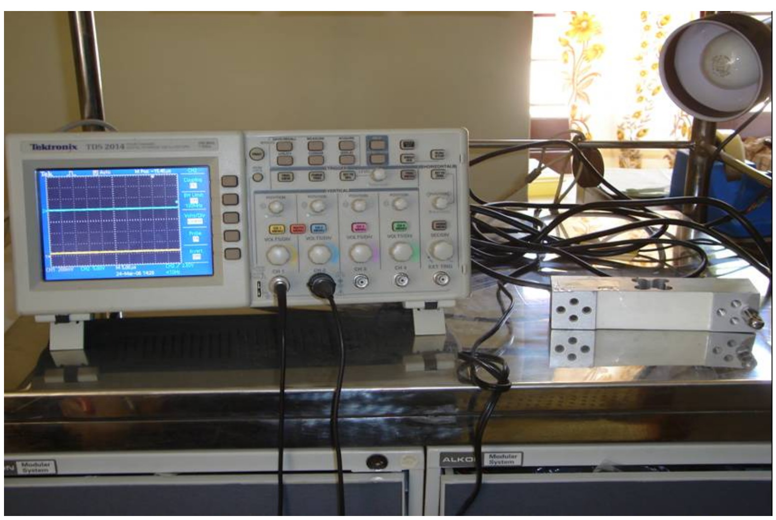
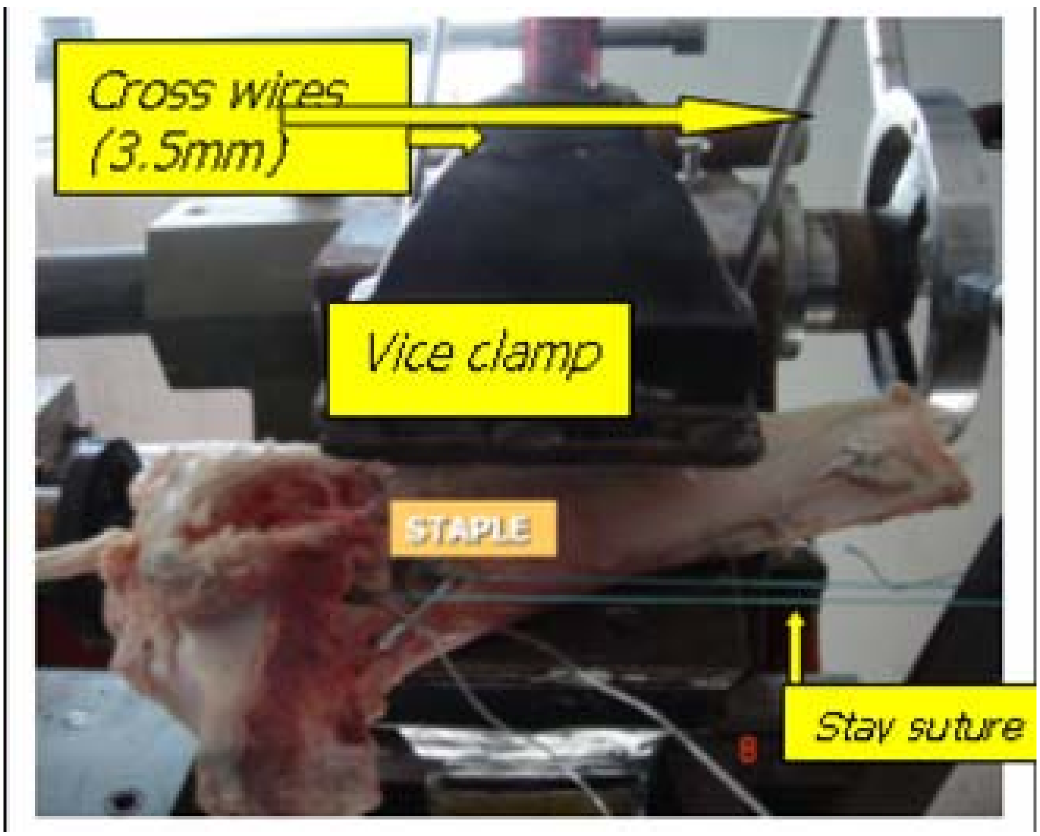


**FIG-10** PRETENSIONING

*The stay suture was fixed to a stand, and the graft was stretched to an initial load of 40N*



The proximal hole was one cm from the bone tendon junction and the second hole was 1cm from the first. The proximal hole was used for fixation of the graft with 20 gauge SS wire *(fig-6)* and 5'ETHIBOND suture *(fig-7)* as explained below. The distal hole was used to pass a stay suture (No.5 polyester) that served to pretension the graft at 40N (explained subsequently).

## **TESTING APPARATUS**:

The tibia was mounted on the vice grip with two cross pins as explained earlier (*fig-4).* The 10x30mm tibial portion of the graft was passed through the 10mm tibial tunnel. A 7mm thick 'S' shaped hook was passed through the patellar end, and attached to the load cell *(fig-8).* The load cell was attached to an oscilloscope where the forces generated were displayed in the form of a graph *(fig-9).* The polyester stay suture attached to the distal tibial bone plug was fixed to a post and the graft was preloaded to 40N. *(fig-10)* This was done by moving the load cell mechanically, to stretch the tendon. (The load cell was attached to a mobile platform that could be moved either proximally or distally using mechanical means or with an electric control that moved the platform at the rate of 1.6mm/sec). The tensile load was monitored for a period of 5min to allow for "creep" of the graft. (Note-the load was applied axial to the tibial bone plug and stay suture). The specimen was subsequently reloaded to 40N for the first part of the study.

**FIG –11** Method of fixation - SS WIRE TO STAPLE
*After knotting the SS wire on the staple, it was tightened using nose pliers*

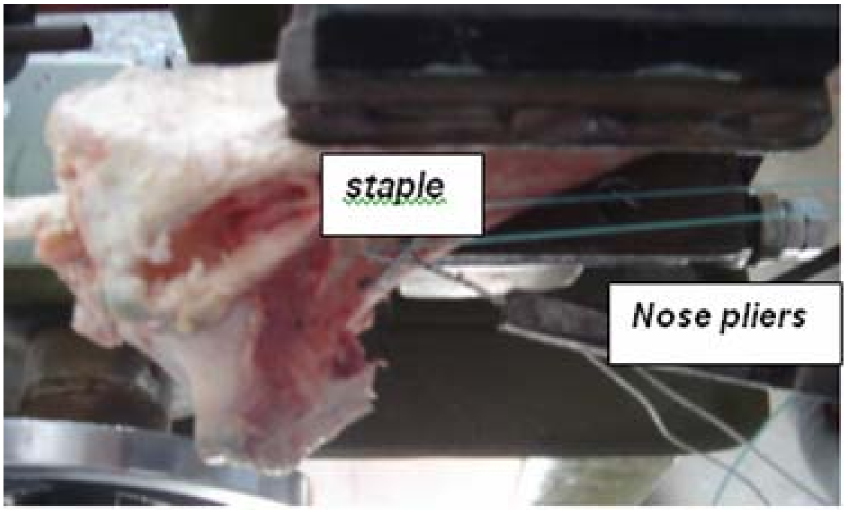



**FIG-12** Method of fixation – No.5ETHIBOND WITH SCREW FIXATION POST
*After three suture are tied on to the screw, it is finally tightened*

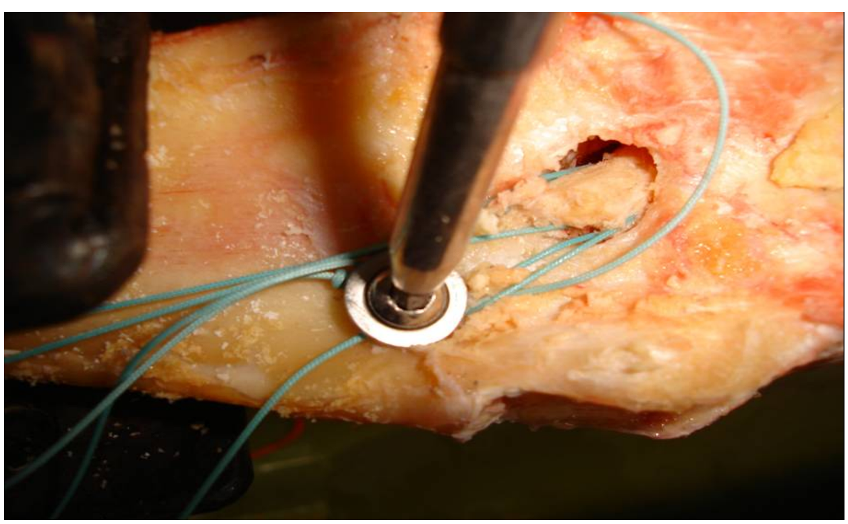


**FIG-13** INTERFERENCE SCREW

## MEASUREMENT OF INITIAL AND RESIDUAL LOAD:

The tibial bone plug was fixed by means of three different fixation techniques i.e. 9x30mm Interference screw, No.5'Ethibond tied onto a screw fixation post (6.5mm cancellous screw with washer) and 20 gauge SS wire fixed to a 20x20mm Staple.

**A. SS Wire to Staple:** The 20G SS wire placed in the bone plug was tied to the 20 x 20mm staple which was inserted distal to the bone tunnel outlet. After initially tying the SS wire on to the staple it was tightened using nose pliers *(fig-11).*

**B. Polyester suture (No.5'Ethibond) to screw fixation post:** The No.5'Ethibond suture placed in the bone plug was tied to a screw fixation post (55 x 6.5 mm cancellous screw with a 1.5mm washer). The screw was inserted distal to the bone tunnel outlet at 30 degree to the bone surface and tightened after the No.5'Ethibond was tied on to the screw *(fig-12).*

**C. Interference screw fixation:** 9 X 30 mm (Smith and Nephew) Titanium Interference Screw. The screw was inserted through the tibial bone tunnel till the end of the screw was flushed with the end of the tibial surface bone block. *(fig 13*)

**FIG –14** SINGLE LOAD –TO-FAILURE TEST

*The tendon graft was stretched at the rate of 1.6mm/sec*

Followed the fixation, the stay suture was cut.

The forces generated in the graft were recorded throughout the fixation period and for 5min thereafter. The ***INITIAL LOAD*** was 40N for all three techniques i.e. the tension in the graft prior to fixation that was applied through the stay suture. The final ***RESIDUAL LOAD*** was the load that was developed in the tendon at the end of fixation of the graft. The data recorded was used to compare the set initial tension and the residual tension in the implanted graft.

## EVALUATION OF PULLOUT STRENGTH, STIFFNESS AND MODE OF FAILURE-

In the next part of the study, the graft, after fixation, was again preloaded to 40N. The tendon graft was stretched at the rate of 1.6mm/sec (the mobile platform on which the load cell was attached was moved at the rate of 1.6mm/sec by an electrical motor) *(fig-14).* The tendon was stretched till failure of the fixation. The ***ULTIMATE FAILURE LOAD*** (The ***PULLOUT STRENGTH*****)** **-** i.e. the maximum tension generated in the graft at the time of failure of fixation- was recorded on the oscilloscope and the ***MODE OF FAILURE*** of the graft was noted. The ***STIFFNESS*** of the graft was assessed by calculating the slope of the linear portion of the force-displacement curve generated during the biomechanical testing.

# RESULTS

## INITIAL LOAD AND RESIDUAL LOAD:

The Initial graft load that was maintained by the stay suture was 40N for all three fixation techniques. The tension developed in the graft during fixation was recorded by the load cell. The Residual load at the end of the fixation was recorded after the stay suture was cut.

The Residual load developed in the graft with three different fixation techniques is shown in the

**TABLE- 2 : RESIDUAL LOAD MEASUERMENT**

**(WITH INITIAL LOAD OF 40N)**

| FIXATION DEVICE | NO | MINIMUM FORCE (N) | MAXIMUM FORCE (N) | MEAN (N) | STANDARD DEVIATION |
|---|---|---|---|---|---|
| STAPLE WITH SS WIRE | 5 | 60 | 132 | **94.00** | 26.306 |
| EHTIBOND WITH SCREW FIXATION | 5 | 56 | 94 | **72.80** | 17.810 |
| INTERFERENCE SCREW | 4 | 36 | 62 | **44.00** | 10.770 |

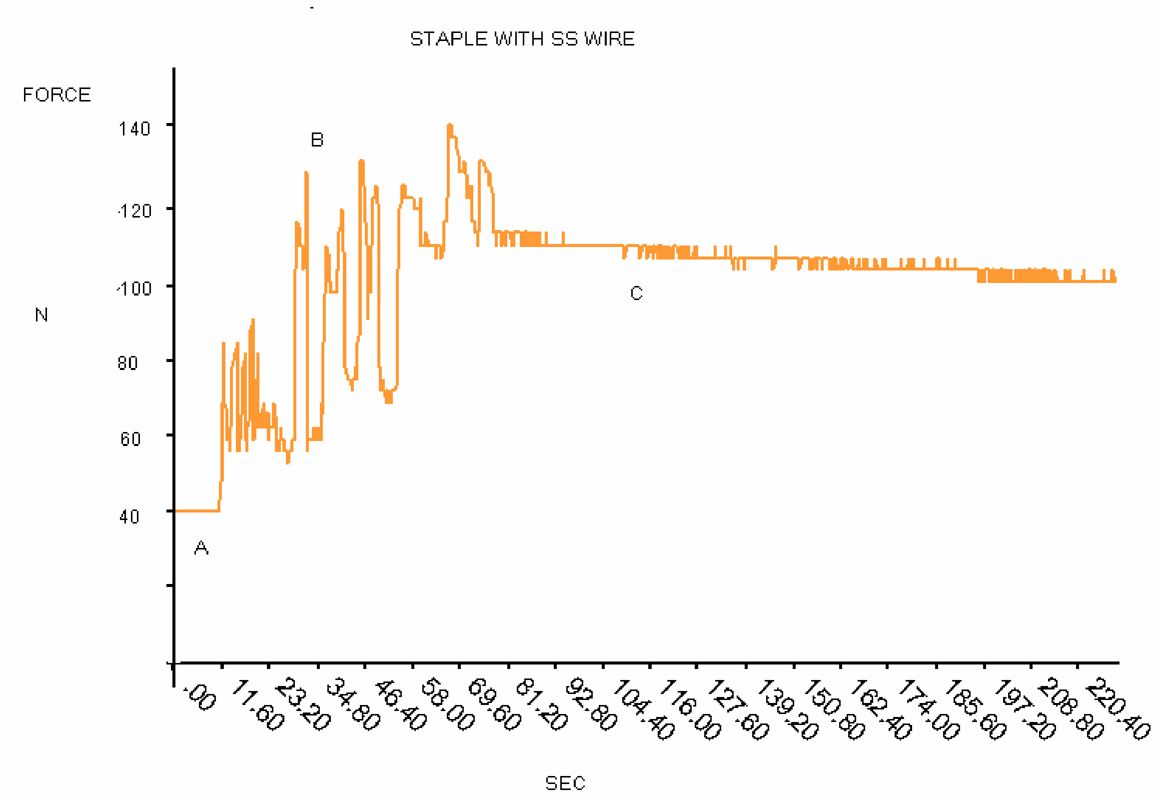
(N- Newtons)

**Note:**

One tibial specimen with Interference screw had to be discarded as the screw was inserted in an oblique manner.

Samples of graphs recorded during and after the fixation of the graft with different techniques are depicted below:

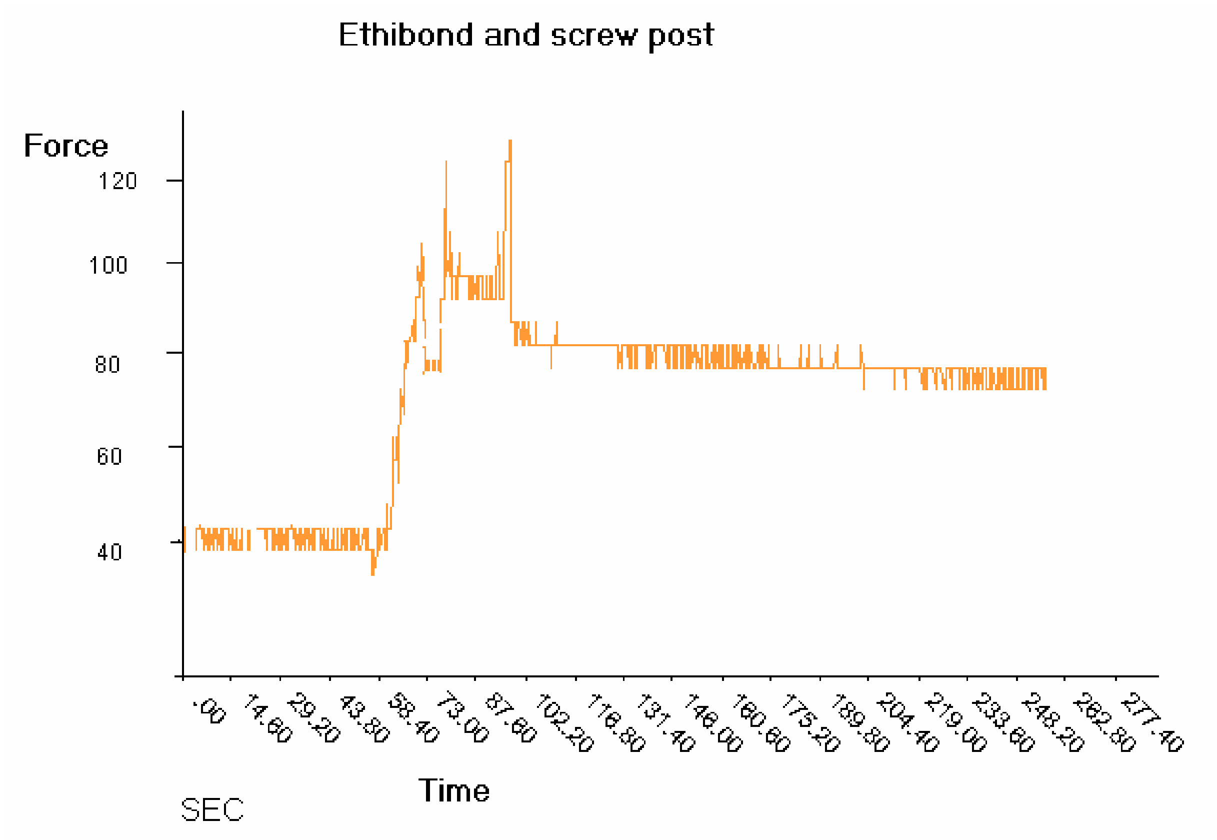
**Fig -15**




*Tendon was stretched at a rate of 1.6mm/second*

***Description of the graph:***

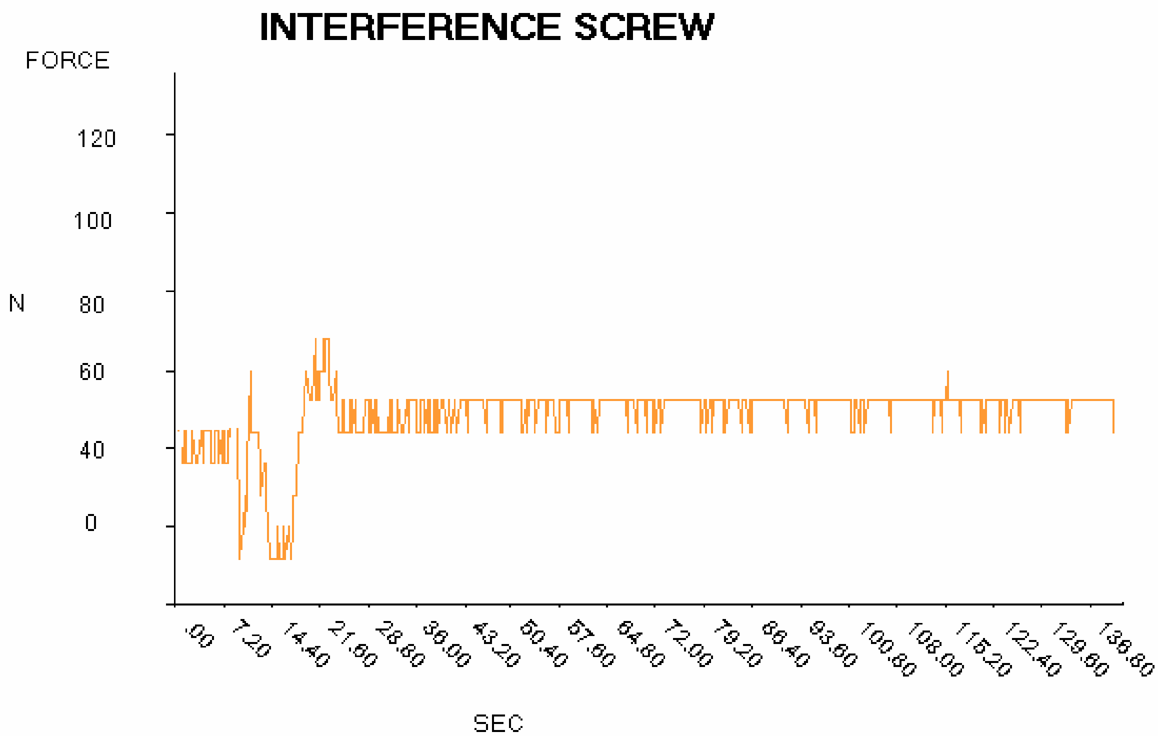
The *Initial Load* was 40N(A). As the SS wire was tightened, the tension gradually increased (B). When the stay suture was cut the *final residual load* was noted(C). In this specimen, the residual load-using staple with SS wire was around 105N.




*Tendon was stretched at a rate of 1.6mm/second*

**Fig-16**

This is a sample of the graph of the forces generated with the use of the N0.5 Ethibond with screw fixation post. The final redidual load in this specimen was 78 N.




*Tendon was stretched at a rate of 1.6mm/second*

***Fig-17***

***Description of the graph:***

The *Initial load* was 40N. While inserting the Interference Screw, the measured load decreased initially, as the tibial bone block was displaced proximally. Subsequently, as the Interference screw engaged the bone block, the tibial bone block was pulled distally and the graft load increased. At the completion of the fixation, the *residual load* applied to the graft was slightly higher than the initial set force with an average of 45 N.

When Wilcoxon signed ranks test was carried out, a statistically significant difference ($p < 0.05$) was observed between the initial load and the residual load when the SS wire with Staples and No5 Ethibond suture with screw fixation post was used as the fixation method. There was no statistically significant difference between the initial load and residual load values for the Interference screw fixation method.

## Table-3

Statistical Analysis of **Initial load and Residual load** using three different fixation techniques (Wilcoxon signed ranks test)

| *Method of fixation* | **p value ( N Par test)** (between Initial Load & Residual load ) |
|---|---|
| STAPLE WITH SS WIRE | P= 0.043 |
| ETHIBOND WITH POST SCREW FIXATION | P= 0.040 |
| INTERFERENCE SCREW | P= 0.465 |

## EVALUATION OF ULTIMATE LOAD FAILURE *( PULL OUT STRENGTH)*

In the second part of the study, we analyzed the pullout strength and stiffness of the bone patellar tendon bone graft. Load displacement curves were obtained with three different fixation methods.

The Examples of force-displacement graphs with the three techniques are shown below:

*X Axis- Time (Displacement was at the rate of 1.6 mm/s)*

*Y Axis- Force Generated*

**Fig-18**

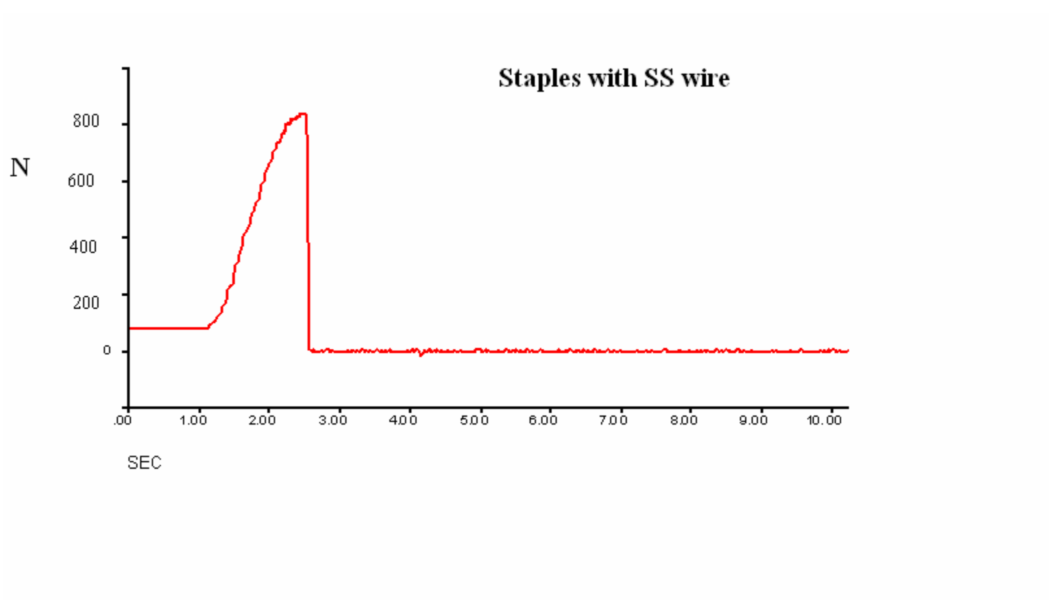


**Fig-19**

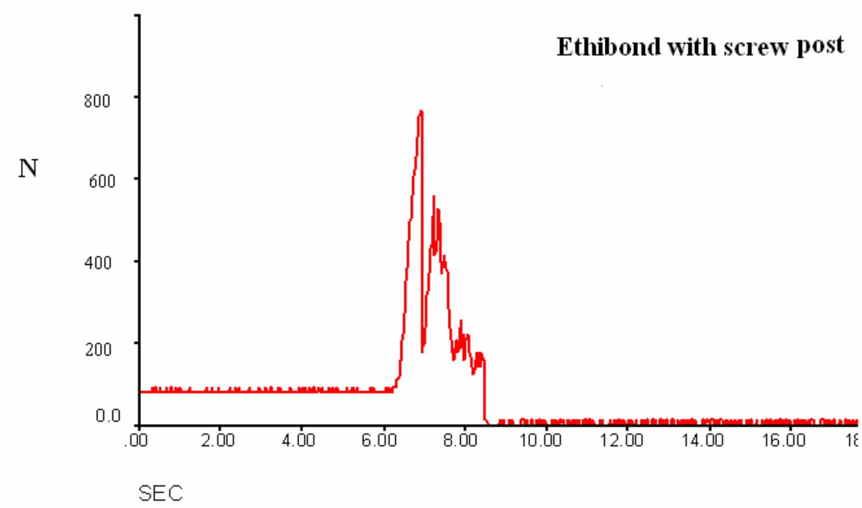

Ethibond with screw post
N
800
600
400
200
0.0
.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
SEC

**Fig-20**

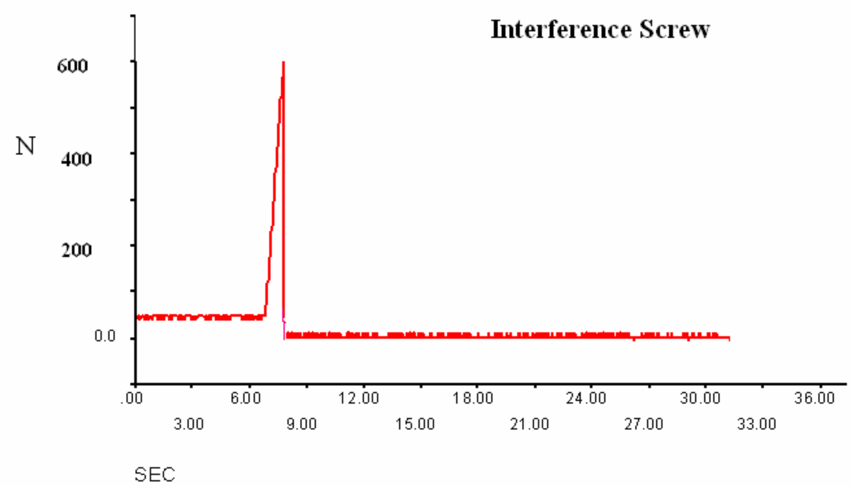



Table 4 below shows the ultimate failure load of the graft fixed with the three different techniques.

## Table-4: PULLOUT STRENGTH MEASUREMENT WITH THREE FIXATION TECHNIQUES

| FIXATION DEVICE | NO. | MINIMUM FORCE (N) | MAXIMUM FORCE (N) | MEAN (N) | STANDARD DEVIATION |
|---|---|---|---|---|---|
| STAPLE WITH SS WIRE | 5 | 640 | 776 | **726.40** | 60.20 |
| ETHIBOND WITH POSTSCREW FIXATION | 5 | 608 | 776 | **733.20** | 72.70 |
| INTERFERENCE SCREW | 4 | 384 | 752 | **594.00** | 173 |

(N-Newtons)

(Note: One tibial specimen with Interference screw had to be discarded as a screw was inserted in an oblique manner)

There was no significant difference between the ultimate failure loads using the three different fixation techniques

## Table-5

Statistical Analysis of **Pullout Strength** of Three Different Fixation Techniques:

(Multiple Comparisons using the Boneferroni Post hoc test was used to analysis statistical significant difference.)

| Groups compared | | Statistical Significant p value | 95 % Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Boundary | Upper Boundary |
| 1 | 2 | **1.000** | -197.77 | 184.17 |
| | 3 | **.277** | - 70.15 | 334.95 |
| 2 | 1 | 1.000 | -184.17 | 197.77 |
| | 3 | **.236** | - 63.35 | 341.75 |
| 3 | 1 | .277 | -334.95 | 70.15 |
| | 2 | .236 | -341.75 | 63.35 |

1- SS wire with staple

2- Ethibond with screw fixation post

3 – Interference screw

## EVALUATION OF *STIFFNESS* USING THE THREE TECHNIQUES:-

The **Stiffness** was assessed by calculating the slope of the linear portion of the force- displacement curve.

For example: **Fig-21**

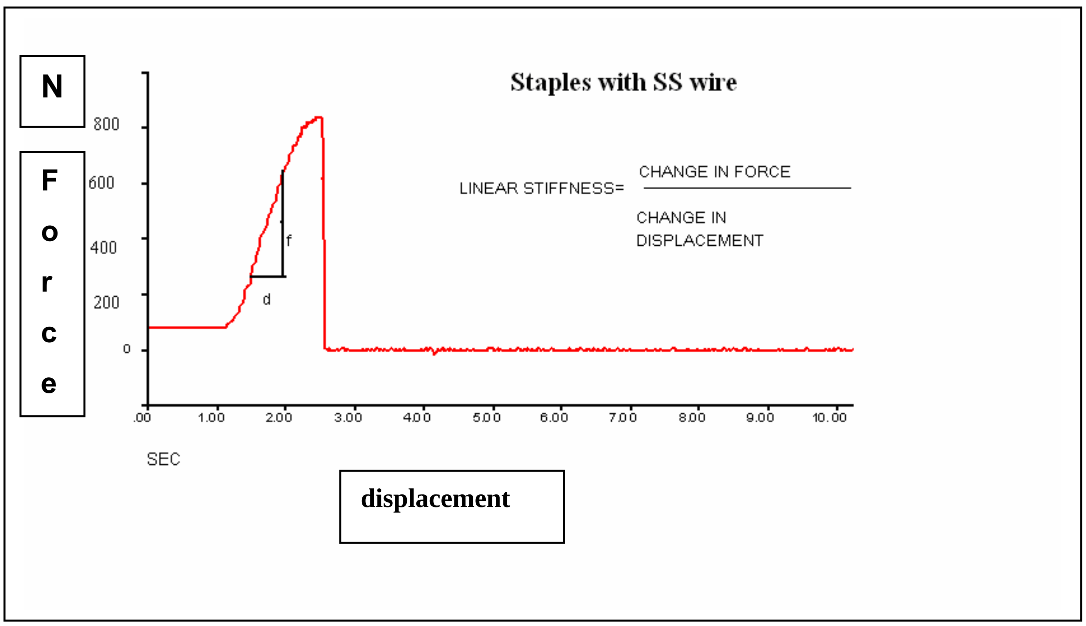


Table 6 Shows the stiffness of the bone patellar tendon graph using three different fixation techniques.

## TABLE-6: *STIFFNESS* WITH THREE DIFFERENT FIXATION TECHNIQUES

| FIXATION DEVICE | NO | MINIMUM FORCE (N) | MAXIMUM FORCE (N) | MEAN (N) | STANDARD DEVIATION |
|---|---|---|---|---|---|
| STAPLE WITH SS WIRE | 5 | 44 | 81 | **61.9** | 13.12631 |
| ETHIBOND WITH SCREW FIXATION POST | 5 | 37 | 63.6 | **53.22** | 10.17802 |
| INTERFERENCE SCREW | 4 | 55.5 | 120 | **79.50** | 28.24299 |

(N-Newtons)

There was no statistical difference in the stiffness using three different fixation techniques.

## Table -7

Statistical Analysis of Stiffness using Three Different Fixation Techniques:

(Multiple Comparison using the Boneferroni ***Post hoc test*** was used to analysis statistical significant difference.)

| Groups compared | | Statistical Significant p value | 95 % Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| 1 | 2 | 1.000 | -23.1187 | 40.4787 |
| | 3 | .507 | -51.3276 | 16.1276 |
| 2 | 1 | 1.000 | -40.4787 | 23.1187 |
| | 3 | .151 | -60.0076 | 7.4476 |
| 3 | 1 | .507 | -16.1276 | 51.3276 |
| | 2 | .151 | - 7.4476 | 60.0076 |

1- SS wire with staple

2- Ethibond with screw fixation post

3 – Interference screw

## EVALUATION OF MODE OF FAILURE

**Staple with SS wire**

Four specimens failed when the SS wire cut through the tibial bone block.

**Figure -22**

In one specimen the SS wire untwisted as the graft was loaded to failure.

**Ethibond with screw post**

All five specimens failed when the Ethibond ruptured.

**Interference screw**

All four specimens failed by pullout of the tibial bone block from the tunnel.

(Note: One specimen was not included for the study as the screw was inadvertently introduced in an oblique manner, leading to a low ultimate failure load.) **Fig-23**

**Summary of Results:**

**TABLE- 8**

| Biomechanical properties | Staple with SS wire (Mean ± SD) | screw fixation post with Ethibond (Mean ± SD) | Interference screw (Mean ± SD) |
|---|---|---|---|
| Residual Load (N) (with initial load of 40N) | 94 ( ± 26.306) | 72.80 (± 17.81) | 44.00 (± 10.77) |
| Pullout strength N) | 726.40(± 60.24) | 733.20(± 72.768) | 594.00 (± 173.605) |
| Stiffness (N/mm) | 61.90 (± 13.126) | 53.22 (± 10.178) | 79.50 (± 28.242) |

**Table- 9**

**Mode of Failure**

| Mode of failure | Staple with SS wire | Ethibond with post screw fixation | Interference screw |
|---|---|---|---|
| Bone Block Pullout | 0 | 0 | 4 |
| Bone Cut Through | 4 | 0 | 0 |
| Breakage of Thread | NA | 5 | NA |
| SS wire untwisted | 1 | NA | NA |

Note : NA- Not Applicable

# DISCUSSION

The Knee joint has been described as a complex hinge joint (19). The ligaments and other supporting soft tissue structures (joint capsule, muscle, tendons and menisci) control the stability of the knee joint (20). The knee joint is between the long lever arms of the femur and the tibia, and consequently, is extremely vulnerable to injuries. The anterior cruciate ligament injury is the most common ligament injury around the knee joint. The ACL, is the primary restraint preventing anterior displacement of the tibia relative to femur and also serves as an important secondary restraint to varus - valgus rotation, as well as internal- external rotation (21).

Noyes et al. (39) reported on the long term disability of ACL injury in active individuals. They found significant functional disability, initially for athletic activities but later for activities of daily living. The discouraging results of non operative treatment can be attributed partially to the associated injuries that occur at the time of ACL rupture. Also the persistent instability leads to significant early degenerative arthritis. Currently, reconstruction with biological graft is the procedure of choice for the treatment of rupture of the ACL.

Biological substitutes used in the intra-articular reconstruction for ruptured ACL are autografts and allografts. The most commonly used autografts are the bone patellar tendon bone (BPTB) graft, multiple strand hamstring tendon and Quadriceps tendon bone graft.  The two commonly used allografts are bone patellar tendon graft and the Achilles tendon - bone graft (28).

The bone patellar tendon bone (BPTB) graft is considered by many as the gold standard for ACL reconstruction (5,28).   The popularity of BPTB graft is based on its structural properties, quality of fixation excellent long-term clinical success and the fact that it provides bone-to-bone healing.  The major concern with the use of BPTB graft has been the donor site morbidity, anterior knee pain, kneeling discomfort, loss of motion, and weakness of the quadriceps muscle (28,29).

The multiple strand hamstring grafts have become increasingly popular as the graft of choice because harvesting causes less graft-site morbidity and function deficit. Hamstring grafts have been shown to have high ultimate failure load and stiffness  - similar or higher to that of normal ACL (28,30).  The demerits of the hamstring tendon graft include failure to achieve rigid initial fixation to bone, slower bone tunnel incorporation compared to the BPTB graft, and increased knee laxity (29).

The quadriceps tendon-bone graft and allograft have also been used for ACL reconstruction . They have been shown to have sufficient structural properties compared to BPTB and hamstring grafts. They are commonly used for revision ACL reconstructions and multiple ligament reconstructions (28).

Evolving methods of graft fixation have been paralleled by marked changes in the post operative rehabilitation program. In the past, prolonged non weight bearing was recommended to protect the graft. New techniques of reconstruction and fixation have changed the emphasis towards early weight bearing. Graft fixation site has been found to be the weakest link in the ACL reconstruction during the immediate postoperative period until biologic fixation occurs (10).

Many methods of graft fixation techniques have been described. Fixation devices have been classified as either direct or indirect (22). Indirect fixations rely on connecting materials, that are attached to the graft, whereas in direct fixation, the graft is fixed directly to the bone.

For the proximal femur, methods of graft fixation include Endobutton, screw and washer, transfixation pins and screws, interference screws, and staples. For the graft fixation on the proximal tibia, methods that have been used include interference screw, staples, sutures tied over a screw fixation post, tandem washers, cross pins, and the Washer Lock system.

For an ideal graft fixation, there should be sufficient initial strength to avoid failure of fixation (i.e. high *pullout strength* or *ultimate failure load* of graft fixation), and sufficient *stiffness* to restore the stability of the knee to avoid gradual loosening in the early post operative period.

The tension of the graft is considered to be an important factor influencing the result of ACL reconstruction (26).Optimal graft tension should be determined so as to restore physiological kinematics of the knee joint.  Studies have shown that a discrepancy exists between the ***initial load*** (i.e. the load applied to the graft during the graft fixation) and the ***residual load (****i.e.* tension in the graft after fixation).  The mechanical behavior during and after fixation is specific to the fixation method employed in the procedure (17,18).

The initial part of the study was conducted to examine how accurately the initial set force of the graft (initial load) can be maintained with different fixation techniques. The initial load (the tension in the graft prior to the fixation) was 40N in all three techniques. The final residual load i.e. the load that developed in the graft at the end of the fixation of the graft was recorded for each fixation device.

The residual load was found to be significantly higher when staple fixation with SS wire and screw fixation post with polyester suture were used to fix the graft. High loads result in difficulty in regaining motion or may lead to articular degeneration from altered joint knee kinematics. Yoshia et al showed in a canine model that over tensioning of the graft resulted in poor graft revascularization and myxoid degeneration within the graft. It would be ideal for the residual load to be as close as possible to the initial set force (initial load). In our study, this was seen to be true for the interference screw fixation. Yokio et al found that the residual load was slightly higher than the initial load when interference screws and screw fixation with ethibond were used – where as the residual load when a button was used for fixation was very much less than the initial load

In the next part of the study the ***Ultimate failure load, Stiffness*** and ***Mode of failure*** were evaluated. The graft after fixation was stretched till failure of fixation occurred. The *ultimate failure load* or *pull out strength* (i.e. the tension generated in the graft at the time of failure of fixation) were recorded on the oscilloscope and the *mode of failure* of the fixation was noted. The *stiffness* of the graft was assessed by calculating the slope of the linear portion of the force-displacement curve generated during the biomechanical testing.

The *ultimate failure load* (or *pullout strength*) was higher with the use of the staple with SS wire fixation and the screw fixation post with polyester suture - when compared with interference screw fixation. This suggests that the interference screw when used for distal fixation in the tibia does not provide sufficient initial strength to avoid failure of fixation. One specimen was not included in this study, as the screw was inadvertently introduced in an oblique manner - leading to a low ultimate failure load. Interference screw divergence - the angle of the interference screw with respect to the bone block, is a common clinical concern, and consequently, its effect on the strength of fixation of BPTB graft has been evaluated biomechanically in others studies. It has been shown that an increase in the divergence angle decreases fixation strength at angles greater than 20 degree. This study seems to suggest that cortical fixation using indirect techniques have a higher pull out strength (though not statistically significant.)

*Stiffness* -the slope of the linear region of the load elongation curve is an important feature of graft fixation. Most indirect fixation methods are less stiff than the interference technique, as they are placed at a distance from the joint cavity - e.g. staple fixation with SS wire and screw fixation post with polyester suture. Sufficient stiffness of the graft fixation constructs not only restores the normal load-displacement response of the knee, but also diminishes graft motion within the bone tunnel. The low stiffness of the graft and the connecting materials allow motion of the tendons within the bone tunnel wall and the graft. Longitudinal and sagittal graft motions within the bone tunnel are also known as the *bungee cord effect and windshield wiper effect*, respectively. If the implant for tendon graft fixation is placed closed to the articular cavity, knee stability increases (28). In our study too, interference screw had higher stiffness values than the other fixation methods. However, it was not statistically significant.

The *mode of failure* was evaluated at the time of failure of the fixation. Grafts fixed with staples and SS wire failed most commonly by cut out of the SS wire. This could potentially have implications in grafts where the bone mineral density of the tibial block is low. In one specimen the stainless steel (SS) wire untwisted as the graft was loaded to failure. When the graft was secured onto a screw fixation post with polyester suture (No.5'Ethibond), the polyester suture broke in all 5 five specimens when loaded to failure. The weakest link proved to be the ethibond suture. It should be noted that though the ultimate failure load was highest when the ethibond suture was used, bone block fracture did not occur in any specimen at the time of failure. With the interference screw, all four specimens failed by pullout of the tibial bone block from the tunnel.

In conclusion, fixation with the interference screw was found to provide good stiffness, and sufficient pull out strength. The interference screw was able to maintain the tension that was initially applied for fixation. Fixation with the staples and SS wire had good pull out strength, and provided sufficient stiffness to the graft –fixation device complex. Fixation with staples and SS wire is a good alternative for fixation of the ACL graft.

# CONCLUSION

The biomechanical properties of bone patellar tendon bone graft fixed with three different techniques in a bovine tibial model were evaluated in this study. The following conclusions were made:

1. The *Initial load* (force applied to the bone patellar tendon graft prior to fixation) was similar to the *Residual load* in the graft after fixation when Interference screw was used to the fix the graft. There was no statistically difference between the Initial load and the Residual load.

2. The Residual load developed in the bone patellar tendon graft after fixation with SS wire to staple and No.5 Ethibond with screw fixation post was higher than the Initial load that was applied to the graft prior to fixation. There was a significant difference in the Initial load and Residual loads with the use of SS wire with staple and No.5 Ethibond to post screw fixation.

3. The SS wire to staple and No.5 Ethibond with post screw fixation has higher *ultimate failure load* than the interference screw fixation. (726.40(± 60.24) and 733.20(± 72.76) (Mean ± SD) respectively.

4. The Interference screw fixation has the lowest *ultimate failure load* 594.00 ± 173.6 N (Mean ± SD).

6. There was however no statistical significance between the ultimate failure load using the three fixation techniques.

7. *Stiffness* of the bone patellar tendon graft was maximum when using the Interference screw, though there was no statistical significant difference when compared to the stiffness of bone patellar tendon graft using other fixation techniques.

8. The bone patellar tendon graft when fixed with SS wire to Staple, failed most commonly by cut out of the SS wire.

9. The bone patellar tendon graft when fixed with No.5Ethibond with screw fixation post, failed by rupture of the thread.

10. The bone patellar tendon graft when fixed with Interference screw, failed by pull out of the bone block.

11. Overall, it appears that the biomechanical properties of the SS wire and staple fixation technique are not much significantly different from that of the Interference screw and it can be used effectively as a substitute fixation method in ACL reconstruction.

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## APPENDIX-1

The following are the individual specimen's biomechanical properties using the three different fixation techniques.

Staple fixation with Stainless Steel wire (Group -1)

| Specimen No. | Initial load (N) | Residual load (N) | Pullout strength (N) | stiffness (N) | Mode of failure |
|---|---|---|---|---|---|
| 1 | 40 | 60 | 640 | 83.3 | SS wire untwisted |
| 2 | 40 | 84 | 752 | 66 | **Bone Cut Through** |
| 3 | 40 | 92 | 776 | 83 | **Bone Cut Through** |
| 4 | 40 | 102 | 776 | 108 | **Bone Cut Through** |
| 5 | 40 | 132 | 688 | 75 | **Bone Cut Through** |

Staple fixation with Stainless wire

| | | |
|---|---|---|
| Residual load | (Mean±Sd) | 94 ( ± 26.306)N |
| Pullout strength | (Mean±Sd) | 726.40(± 60.24)N |
| Stiffness | (Mean±Sd) | 61.90 (± 13.126)N |

Screw fixation post with Polyester suture (Group-2)

| Specimen No. | Initial load (N) | Residual load (N) | Pullout strength (N) | stiffness (N) | Mode of failure |
|---|---|---|---|---|---|
| 1 | 40 | 56 | 776 | 83.3 | **Breakage of Thread** |
| 2 | 40 | 64 | 730 | 75 | **Breakage of Thread** |
| 3 | 40 | 60 | 776 | 100 | **Breakage of Thread** |
| 4 | 40 | 90 | 608 | 50 | **Breakage of Thread** |
| 5 | 40 | 94 | 776 | 100 | **Breakage of Thread** |

Screw fixation post with Polyester suture

Residual load (Mean±Sd) 72.80 (± 17.81)N

Pullout strength (Mean±Sd) 733.20(± 72.768)N

Stiffness (Mean±Sd) 53.22 (± 10.178)N

Interference screw fixation (Group 3)

| Specimen No. | Initial load (N) | Residual load (N) | Pullout strength (N) | stiffness (N) | Mode of failure |
|---|---|---|---|---|---|
| 1 | 40 | 36 | 752 | 60 | **Bone Block Pullout** |
| 2 | 40 | 38 | 720 | 103 | **Bone Block Pullout** |
| 3 | 40 | 46 | 384 | 83 | **Bone Block Pullout** |
| 4 | 40 | 62 | 520 | 120 | **Bone Block Pullout** |

Interference screw fixation

| | | |
|---|---|---|
| Residual load | (Mean±Sd) | 44.00 (± 10.77)N |
| Pullout strength | (Mean±Sd) | 594.00 (± 173.605)N |
| Stiffness | (Mean±Sd) | 79.50 (± 28.242)N |

## APPENDIX-II

## The DEXA scan report of a tibial specimen is enclosed

lephone: 0416-2222102 Ext 2553,3047 E-Mail: nuclear@cmcvellore.ac.in Fax: 04

ame: A-2
tient ID: 000002C
OB: 03 March 2001

Sex: Male
Ethnicity: Asian

Height: 1
Weight:
Age: 5

erring Physician: DR ANBU SURESH


116 x 152

## Scan Information:

Scan Date: 08 March 2006 ID: A0

Scan Type: a Lumbar Spine

Analysis: 08 March 2006 11:02 Version 11
Lumbar Spine

Operator:

Model: Delphi W (S/N 70471)

Comment:

## DXA Results Summary:

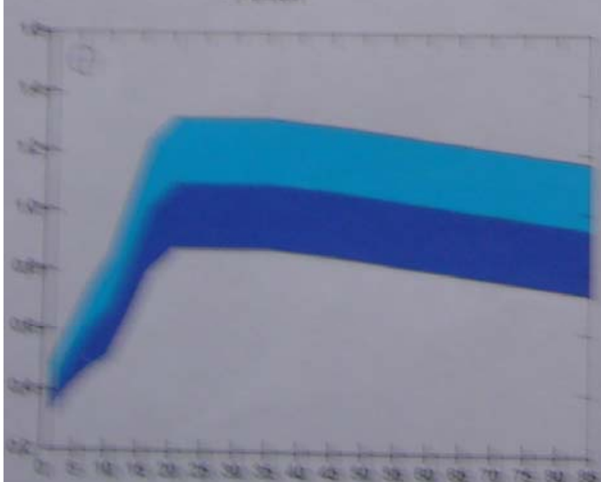
| Region | Area (cm²) | BMC (g) | BMD (g/cm²) |
|---|---|---|---|
| L1 | 20.47 | 29.72 | 1.452 |
| L2 | 39.79 | 52.18 | 1.311 |
| L3 | 28.11 | 44.89 | 1.597 |
| L4 | 19.06 | 34.46 | 1.808 |
| Total | 107.43 | 161.25 | 1.501 |

Total BMD CV 1.0%

WHO Classification: Normal

Fracture Risk: Not Increased

Total




## Physician's Comment:

curve and scores matched to White Male

# ABSTRACT

**Assessment of the biomechanical properties of anterior cruciate ligament reconstruction using different techniques of fixation in a bovine knee model.**

**Aim:** To evaluate the biomechanical properties of bone patellar tendon bone graft ( BPTB) fixation with different techniques in a bovine model.

**Introduction:** Intra-articular reconstruction with a biologic tendon graft is the procedure of choice for restoring stability of a knee after rupture of the anterior cruciate ligament (ACL). Rigid fixation of the bone block in the tunnel is crucial for initial strength of the graft. Fixation with the help of an Interference screw is considered as the gold standard. Indirect fixation using polyester suture tied to a screw fixation post, and *SS (Stainless Steel) wire* tied to staples placed inferior to the bone tunnel outlet are other alternative techniques. This study was performed to evaluate the primary biomechanical parameters of three different fixation techniques –

a) *Staple fixation with SS wire*

*b) Polyester suture tied onto a screw fixation post*

*c) Interference screw.*

**Methods:** Fifteen fresh bovine knees and bovine patellar tendons were used for the study. The BPTB graft was fixed to the tibia using the three different fixation techniques mentioned above. The patella was fixed to a load cell, and forces generated in the graft were recorded.

In the first part of the study, the BPTB was pretensioned to an initial tension (or *initial load*) of 40N. The graft was then fixed using the three different methods, and the changes in tension (load) in the graft during fixation were recorded. The *residual load* in the graft after fixation was recorded and compared to the initial load (i.e. 40N in all instances).

In the second part of this study, the graft was subjected to a single load-to-failure test, and the following parameters were recorded - *ultimate failure load* (*the pullout strength), stiffness, and mode of failure*.

**Result:** Though the BPTB graft was fixed with an *initial load* of 40N, the graft tension at completion of fixation (*residual load*) with staple and SS wire, screw post with polyester suture and Interference screw was 94.00N, 72.80N, and 44.00 N respectively.

In the single load-to-failure biomechanical testing, *the ultimate failure load (pullout strength)* and *stiffness* for Staple with SS wire was 726.40N and 61.9N respectively, for the Screw fixation post and polyester suture - 733.20N and 53.22N, and for Interference screw -594.00N and 79.50 N. There was no statistically significant difference in the stiffness and ultimate failure load using the three fixation techniques.

In 4 specimens, the Staple with SS wire fixation failed when the SS wire cutting through the bone. In the fifth specimen, the SS wire untwisted during loading. With the screw fixation post, the polyester suture broke in all 5 specimens. With the interference screw, all failed by bone block pull out.

**Conclusion:** There was a significant difference in the *initial* and *residual load* with use of staple fixation with  SS wire and screw fixation post with polyester suture. When interference screw was used for fixation, initial load was similar to the residual load. The *pullout strength* of staple fixation with SS wire and screw fixation post with polyester suture was higher than when interference screw was used. *Stiffness* was higher with use of interference screw. However, the differences between three techniques was not statistically significant.